

The mechanism of acidification of soil by *Calluna* and *Ulex* and the significance for conservation

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Introduction

The work reported here has been carried out in relation to a specific problem of management in a particular community, chalk heath, but we believe that it has implications for the conservation of a variety of plant communities with a topsoil pH in the range 5–6. Chalk heath is an intimate mixture of the usual chalk grassland plants with heather (*Calluna vulgaris*) or bell heather (*Erica cinerea*). It is found on shallow loam soils over flints over chalk (Fig. 1). Depending on parent materials the loam may be a clay loam, silty loam or sandy clay loam; the organic matter content is *c.* 10–50 per cent. At the site we have studied in detail (Lullington Heath National Nature Reserve, National Grid Reference 51/544017) the loam is a silty loam (largely loess-derived), generally about 10–15 cm deep and with an organic matter content of 20–50 per cent.

The intimate mixture of calcicoles and calcifuges in chalk heath is stable so long as the topsoil pH remains in the range 5–6 and is thus of particular scientific interest in demonstrating that the constituent species have overlapping pH tolerances (Grubb *et al.* 1969). Historically the intimate mixture has been maintained for centuries under grazing by sheep and rabbits. Grazing by sheep on most of the chalk in England came to an end early this century and grazing by rabbits virtually stopped as a result of myxomatosis in 1954; there have been only minor recoveries by rabbits at Lullington Heath since 1954.

The consequences for chalk heath of a cessation of grazing are shown in outline in Fig. 1 (for a fuller account see Grubb *et al.* 1969). Bushes of *Calluna*, *Erica* and *Ulex* rapidly acidify the soil and, if they are cleared, a new mixture of calcifuges and indifferent species is established—the original chalk heath mixture is lost.

At Lullington most of the chalk heath has changed into *Ulex* scrub.

Clearance of more *Ulex* scrub cannot by itself be regarded as a policy of value in conserving chalk heath. It is highly desirable that we try to obtain a full understanding of the mechanism of soil acidification so that we have a sound theoretical basis for developing some practical means of reversing the process.

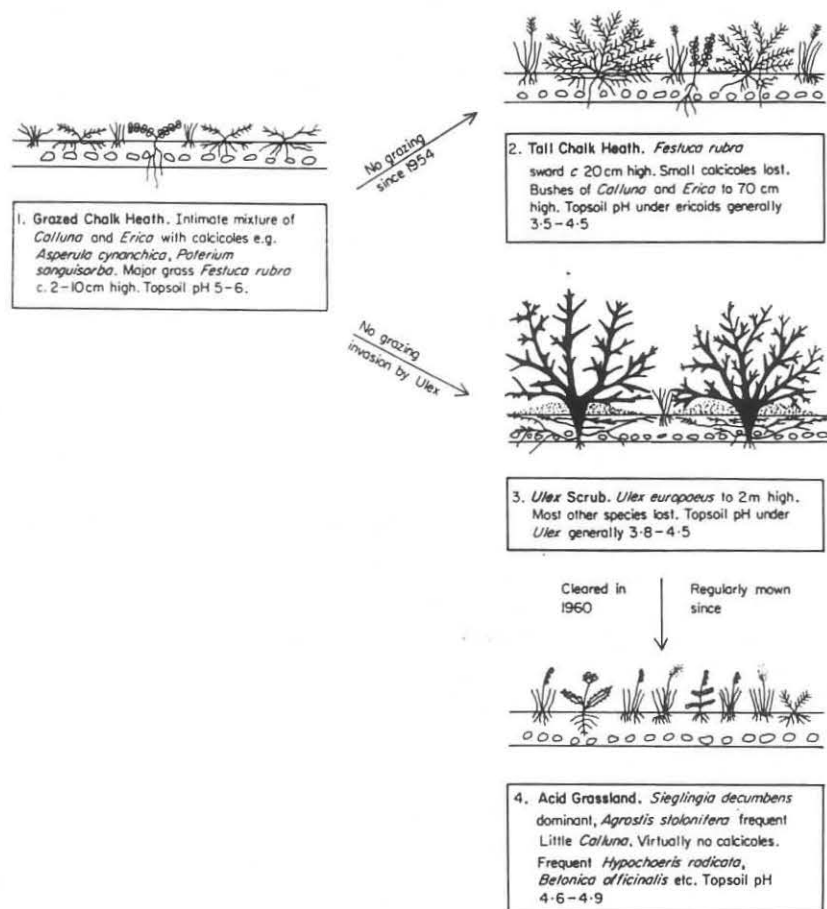


Figure 1. A summary of the effects on chalk heath of a cessation of grazing and of the effects of clearance of gorse scrub derived from chalk heath.

There appear to have been very few studies aimed at determining precisely the mechanism of acidification of soil by plants. We shall discuss the limited information in the literature when we have given an account of our own work.

Our approach has been to ask the following questions.

- 1 Is any of the acidification due to addition of mineral acids, e.g. sulphuric or nitric, released perhaps by microbial processes?
- 2 Is any of the acidification due to addition of organic acids, e.g. citric or oxalic, derived perhaps from the litter.

- 3 Is any of the acidification due to addition of new exchange sites for cations, provided by humic acid *sensu lato*?
- 4 Is any of the acidification due to removal of bases and, if so, what parts of the cycle of bases in the community are affected?

Methods

All analyses of soil (except those for nitrate and titratable acidity) have been made on material passing a 2 mm sieve; extracts have been made of fresh soils within a few days of collection. All analyses of plants have been made on digests prepared with a mixture of concentrated nitric and perchloric acids (5:1). Roots have been washed repeatedly in demineralized water. Results of various analyses are expressed on a dry weight basis; subsamples of all material were dried at 105°C for 24 hours.

pH has been determined electrometrically on samples brought to a paste with demineralized water. Nitrate has been extracted with a dilute copper sulphate solution from unsieved soils dried for 24 hours at 50°C 2 days after collection and determined spectrophotometrically after reaction with phenol 2,4-disulphonic acid (Jackson 1958). Sulphate has been extracted with cold water and determined by back titration of barium chloride with versene and Eriochrome Black T indicator (Jackson 1958). Soluble acids have been extracted with cold water (50 ml per 15 g of dry soil for 14 hours) and determined with barium hydroxide (phenolphthalein indicator). Cation exchange capacity (C.E.C.) at pH 7 has been determined by a modification of the method of Jackson (1958, p. 61). C.E.C. at field pH has been determined similarly but with all solutions (other than the 80 per cent acetone) brought to the required pH with acetic acid or hydrochloric acid beforehand. Exchangeable cations have been extracted with N ammonium acetate at pH 7. Potassium and sodium have been determined by emission flame photometry; calcium and magnesium by atomic absorption flame photometry after addition of lanthanum chloride to suppress interference. Organic matter in the soil has been determined by ignition at 375°C (Ball 1964); the calcium carbonate content is <0.002 per cent in loamy topsoil (Grubb *et al.* 1969).

The nomenclature follows Clapham *et al.* (1962).

Results

Nature of increased acidity

Mineral acids

Some analyses of nitrate are shown in Table 1. There is no marked increase

under either *Calluna* or *Ulex*. Lehr (1950) found that 40 $\mu\text{g/g}$ $\text{NO}_3\text{-N}$ were needed to reduce the pH of a sandy soil with little buffering power from 5.5 to 4.5. The values for $\text{NO}_3\text{-N}$ that we have obtained are much smaller (c. 0.5–5.0 $\mu\text{g/g}$). Furthermore, our soil is better buffered; an addition of 40 $\mu\text{g/g}$ of $\text{NO}_3\text{-N}$ as nitric acid reduces the pH from 5.2 to 5.0 only. The values we have obtained for sulphate (soils sampled 16 January 1970) are also low and show no evidence of an increase with fall in pH.

Table 1. Concentrations of nitrate-nitrogen and titratable acidity in extracts of topsoil (0–2 cm) under tall *Festuca rubra*, under *Calluna* and under *Ulex*. Soils sampled 22 June 1970.

	<i>Festuca</i>	<i>Calluna</i>	<i>Ulex</i>
(a) Nitrate-N ($\mu\text{g/g}$ D.W.)			
Mean	2.84	0.97	3.05
Range	0.67–9.34	0.40–1.47	0.67–5.69
Number of samples	4	6	3
pH range	5.1–5.6	3.7–4.2	3.6–3.8
(b) Titratable acidity (m.equiv./100 g D.W.)			
Mean	0.12	0.54	0.33
Range	0.10–0.13	0.52–0.57	0.30–0.35
Number of samples	2	2	2
pH range	5.1–5.3	3.7–4.2	3.6–3.8

Organic acids of low molecular weight

These have been estimated indirectly as titratable acidity in water extracts (Table 1). If all the nitrate and sulphate that we have measured is present as nitric and sulphuric acids, they will account for 0.04 and 0.11 m equiv./100 g dry soil at most. Together they may therefore account for the acidity of extracts of soil under *Festuca*. They cannot, however, account for the acidity of extracts of soil under *Calluna* and *Ulex*. We have no values for water-soluble phosphoric acid but it seems unlikely that it will be present in greater quantity at low pH. We conclude that there probably is a small increase in the organic acids in the soil under *Calluna* and *Ulex*. The increase amounts to 0.5 m equiv./100 g at most and is unlikely to contribute much directly to the soil's acidity. However, the acids concerned may be active in the process causing acidification (see p. 130).

Cation exchange sites

The cation exchange capacity (C.E.C.) at pH 7 is found to decrease rather than increase as a part of the acidification process under *Calluna* and *Ulex*. Some data for *Calluna* are set out in Fig. 2. The points in Fig. 2a suggest a

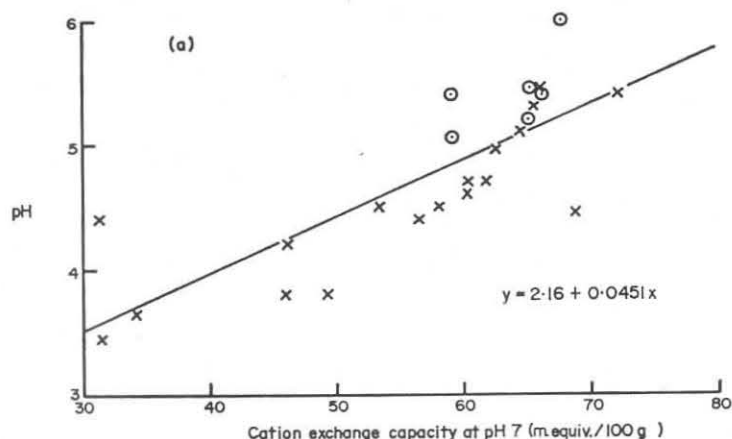


Figure 2a. The relationship between pH and cation exchange capacity at pH 7: samples at 0-2 cm taken from under turf of *Festuca rubra* (○) and from under bushes of *Calluna vulgaris* of a range of sizes (x).

curved relationship but other sets of determinations we have made, e.g. those

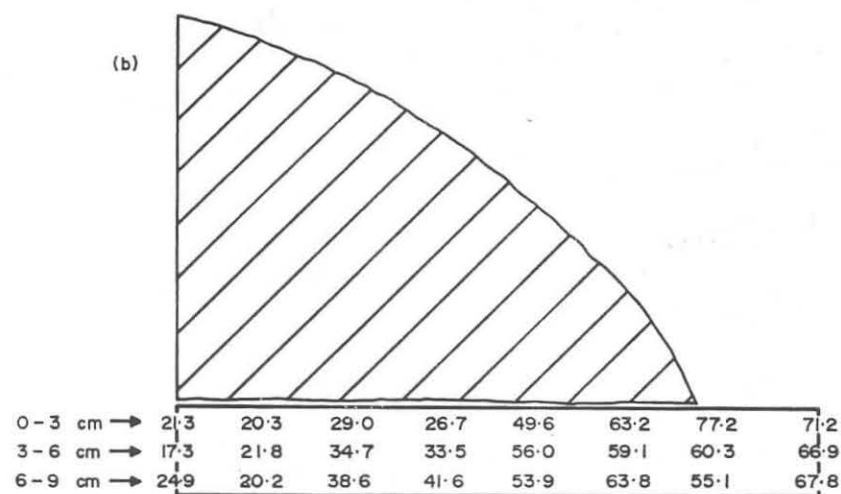


Figure 2b. The relationship between cation exchange capacity and position in the soil underneath and outside a *Calluna* bush: readings taken 15 cm apart, bush 65 cm high.

for Fig. 2b, all fit linear plots. C.E.C. at field pH is likely to fall even more as a function of pH than C.E.C. at pH 7 because of blocking of exchange sites by polymers of the hydrated aluminium ion (Black 1968). The few data we have on C.E.C. at field pH are consistent with this expectation. In a highly organic loam like that at Lullington most of the exchange sites are likely to reside in the organic matter. It is therefore interesting that the loss on ignition at 375°C is not significantly related to pH. Eighty-nine determinations at pH 3.5–6.0 in the top 2–3 cm of 'mineral' soil have given a mean 36.80 per cent ± 0.72

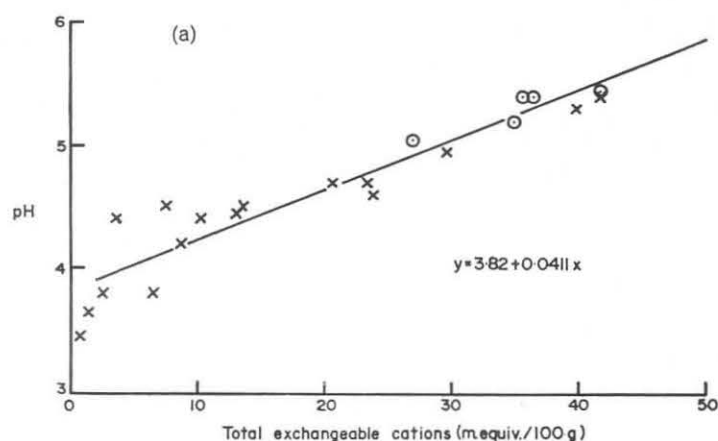


Figure 3a. The relationship between pH and total exchangeable cations: samples as for Fig. 2a.

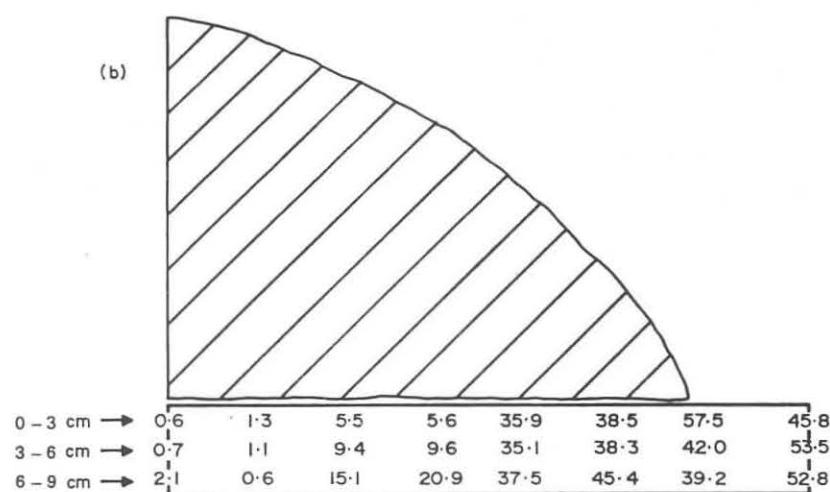


Figure 3b. The relationship between total exchangeable cations and position in the soil underneath and outside a *Calluna* bush: samples as for Fig. 2b.

per cent (S.E. of the mean). The values for 3–6 cm and 6–9 cm are 26.91 per cent ± 0.63 per cent and 25.5 per cent ± 0.74 per cent respectively (16 determinations at each level).

Exchangeable cations

The content of total exchangeable cations, as conventionally defined (Ca, Mg, K, Na), falls very markedly with decrease in pH under both *Calluna* and *Ulex*. Some data for *Calluna* are shown in Fig. 3. The decrease in total exchangeable cations is relatively greater than that in cation exchange capacity so that base saturation falls from c. 80 per cent at pH 6 to c. 10 per cent at pH 4 (Fig. 4). Calcium is the dominant cation at pH 6 and loss of calcium accounts for most of the decrease in total exchangeable cations (c. 20 m equiv./100 g per 1.0 pH

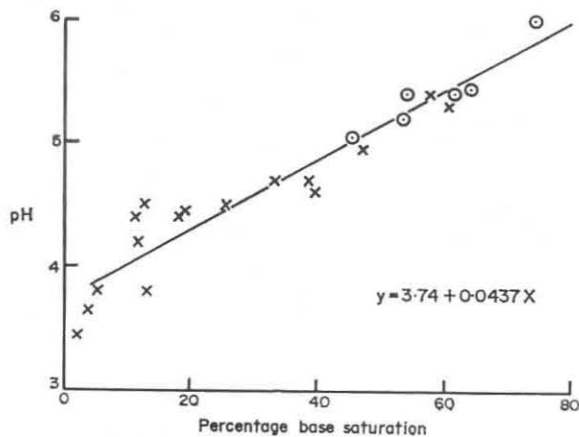


Figure 4. The relationship between pH and percentage base saturation: samples as for Fig. 2a.

unit). The changes in exchangeable magnesium, potassium and sodium are more complex and less regular; where they do show a decrease, this amounts to only c. 1.0, c. 0.7 and c. 0.5 m equiv./100 g per 1.0 pH unit). It is planned to discuss these changes in more detail elsewhere.

Summary

There is no evidence that acidification is due to an increase in mineral acids, in organic acids of low molecular weight or in humic acid *sensu lato*. Loss of cations seems to be the chief cause of increased acidity.

Changes in the cycling of bases

A summary of the movements of bases through a generalized plant is set out

in Fig. 5. There are at least four situations which can lead to a net loss from the topsoil.

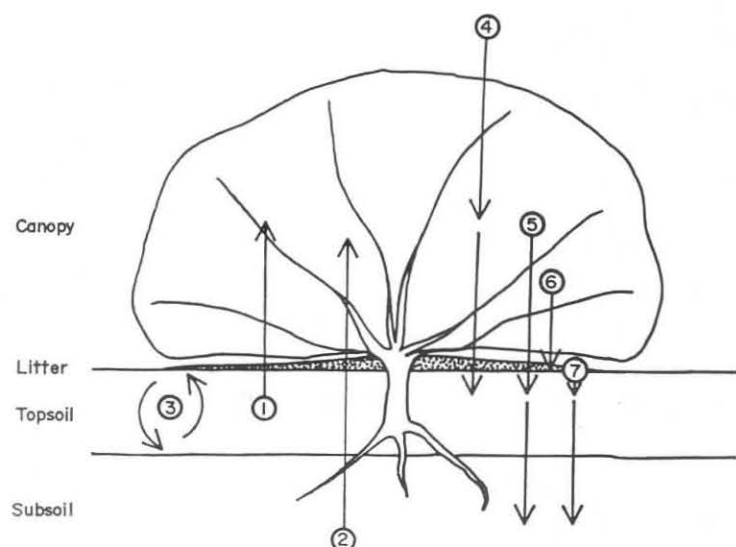


Figure 5. A summary of the major movements of bases through and under a generalized plant: 1. Uptake from the topsoil; 2. Uptake from the subsoil; 3. Mixing of soil by animals especially earthworms; 4. Supply via rain and dust; 5. Leaching of canopy; 6. Shedding of litter; 7. Leaching of litter.

1 A plant may immobilize the bases that it has taken up into its shoots; it may shed very little litter, form a litter that decays very slowly or suffer negligible leaching.

2 A plant may have very few or no deep roots exploiting the subsoil.

3 A plant may inhibit the activities of animals that mix up the soil profile, particularly the surface-casting earthworms.

4 A plant may produce from its shoots or its litter organic compounds that form complexes with bases and accelerate leaching down the profile.

We can consider briefly each of these possibilities.

Immobilization of calcium in the plant

The major base lost is calcium and we present here only the data for calcium. In assessing the present position we have made an allowance for the calcium immobilized in the plants of the short chalk heath which occupied the soil before the development of a given bush of *Calluna* or *Ulex*. We estimated this amount by sampling the short chalk heath at Lullington maintained by mowing (cf. Grubb *et al.* 1969, p. 191). This closely resembles the grazed chalk heath of pre-1954 days but is rather taller. Unfortunately the determina-

tions were not made at the same time as those of other fractions but in July 1970. The way in which we have subdivided bushes for sampling and analysis is shown in Table 2; one fraction included is that of suppressed and dying chalk heath plants included within the area of the bush.

Table 2. The weights of the different fractions of selected *Calluna* and *Ulex* bushes and of short chalk heath plants on an equivalent area, together with calcium concentrations and contents.

Fraction	<i>Calluna</i> bush 2			<i>Ulex</i> bush 2		
	Dry weight (g)	Calcium concentration (m.equiv./g.)	Calcium content (m.equiv.)	Dry weight (g)	Calcium concentration (m.equiv./g)	Calcium content (m.equiv.)
Green small shoots	874	0.199	174	9621	0.189	1819
Old small shoots	918	0.073	67	7569	0.180	1364
Larger branches	715	0.069	49	7739	0.056	436
Roots	576	0.165	95	2252	0.161	363
L Litter	626	0.126	79	2004	0.154	309
F Litter	771	0.208	160	340	0.412	140
Grass etc under bush	418	0.267	111	2633	0.356	938
Total	4898	—	735	32158	—	5369
Short chalk heath on an equivalent area						
Shoots	643	0.3014	194	3312	0.3014	998
Roots	1619	0.4674	758	8340	0.4674	3906
Total	2262	—	952	11652	—	4904

The calculation of the amount of calcium lost from the soil beneath a bush is made relatively easy by the linear relationship between pH and concentration of exchangeable calcium. The collected data for *Ulex* are given in Fig. 6. The comparable regression for *Calluna* is $y = 3.79 + 0.0451x$ (40 determinations). We have made transects of the soil beneath the bushes, measuring the pH at three levels, generally 0–3 cm, 3–6 cm and 6–9 cm. We have used the results at each level to make maps of pH, isolating arbitrarily areas with a reasonably narrow pH range (Fig. 7). Arithmetic mean values of pH have been calculated for each area at each level. It is assumed that the mean pH of the unacidified area is approximately the same as the mean pH was in the area now acidified before the bush grew up. Then it is possible to calculate the calcium lost for each segment showing acidification, using the regressions given

in Fig. 6 and above, together with values for bulk density determined on blocks of soil 15×15 cm in area and corrections for flints in the 6–9 cm layer.

The results of comparing calcium lost and calcium immobilized are shown for four bushes in Table 3. It appears that in the case of *Calluna* the

Table 3. Amounts of calcium immobilized in, and lost from beneath, four bushes, together with other relevant data.

Bush	Time of sampling	Mean pH outside bush	Lowest recorded pH at 0–3 cm	Dry weight of bush and litter (g)	Calcium immobilized (m.equiv.)	Calcium lost (m.equiv.)
<i>Calluna</i> 1	Oct. 69	5.2	3.5	8136	– 548 ¹	3350
<i>Calluna</i> 2	May 70	5.2	3.4	4898	– 217 ¹	1512
<i>Ulex</i> 1	Mar. 70	5.7	4.3	39056	806	1793
<i>Ulex</i> 2	Apr. 70	5.2	4.0	32158	465	3261

¹ Minus sign indicates that there is less calcium in the *Calluna* than in an equivalent area of short chalk heath.

calcium lost far exceeds that immobilized. Indeed there has been no immobilization by the bushes but rather a net loss from the system; calcium lost under *Ulex* considerably exceeds that immobilized. The possible errors in our comparison are many and hard to evaluate. We cannot discuss them in detail here, but we believe that they are unlikely to be so large as to change the conclusion for *Calluna*. In the case of *Ulex* we cannot yet reach any firm conclusion, but the position is similar to that for *Calluna*. Further, *Ulex* has many roots running through the calcareous, flinty loam–chalk boundary (Fig. 1) and these presumably take up an appreciable amount of calcium without causing any acidification—the pH of calcareous soil being so effectively buffered against loss of calcium. Therefore we should expect immobilization in the plant to exceed apparent loss from the soil by a wide margin, if acidification is effected solely by immobilization.

Occurrence of deep rooting

As indicated above, failure of deep rooting certainly cannot be considered a means of changing the cycling of the bases through *Ulex*. On the other hand *Calluna* develops very few, very small roots in the calcareous subsoil. It is hard to assess the contribution to acidification of this failure to form deep roots. The unacidified chalk heath had only a certain proportion of species with marked deep-rooting, e.g. *Poterium sanguisorba* (Fig. 1). Other calcicoles that were common develop most of their roots in the loam top soil, e.g. *Filipendula vulgaris* and *Scabiosa columbaria* (Figs. 4 and 5 in Grubb *et al.* 1969). We hope to be able to present figures on the importance of this issue in a later publication.

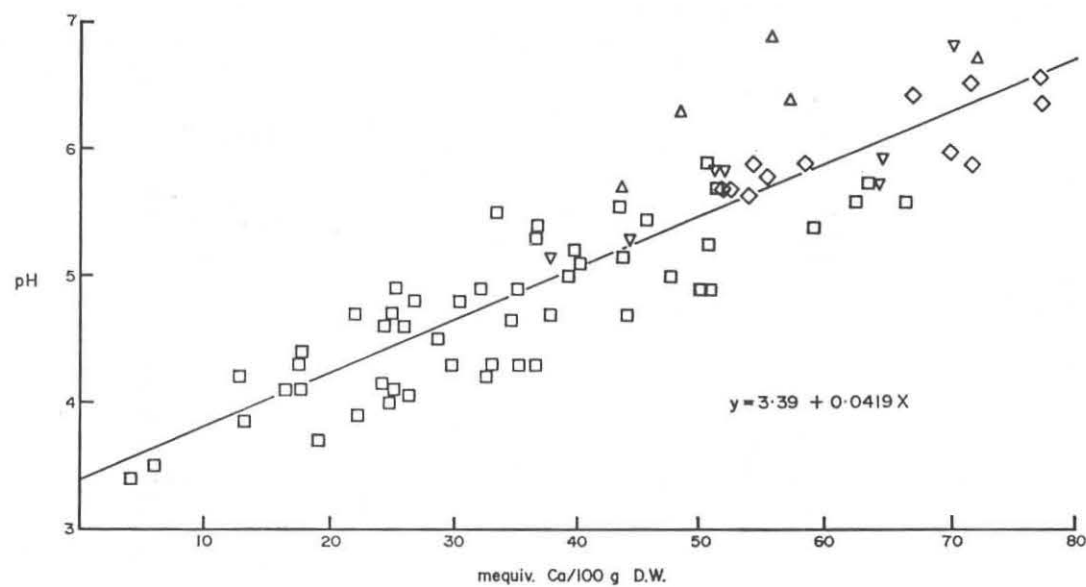


Figure 6. The relationship between pH and exchangeable calcium in soil under *Ulex*. Samples taken from 0-2 or 0-3 cm (□), 3-6 cm (▽), 6-6 cm (△) and 3-9 cm (◇).



Figure 7a, b. For explanation see next page.

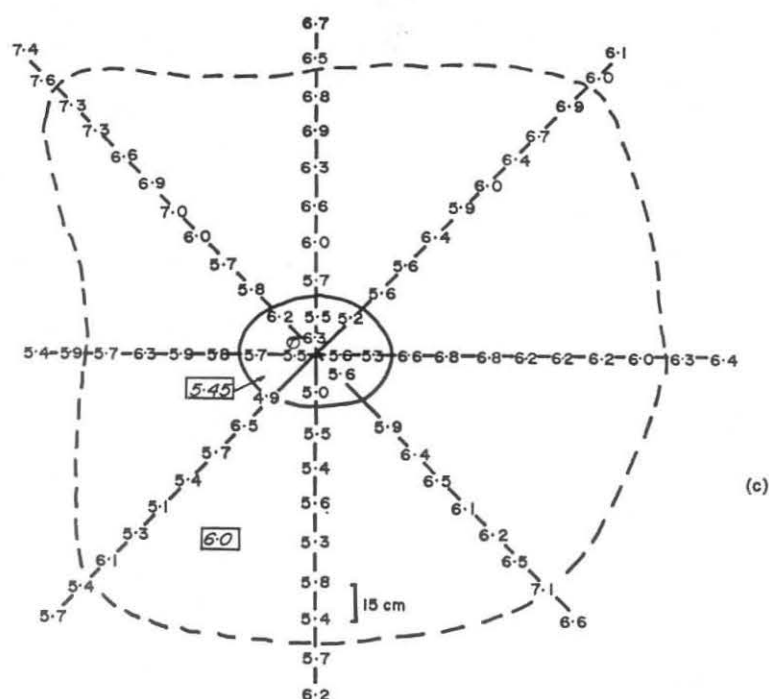


Figure 7. Transects of pH under a *Ulex* bush at three levels (a) 0–3 cm, (b) 3–6 cm, (c) 6–9 cm. The main samples were 15 cm apart. * signifies that a high density of worm casts was noted at this point. † signifies that flints were present at depth < 6 cm. The 'contours' separate areas with the mean pH's indicated in italics. The pecked lines indicate the outline of the bush.

Activities of surface-casting earthworms

Some values for the amounts of recognizable worm casts in tall chalk heath, under *Calluna* and under *Ulex* are given in Table 4 and some values for numbers and weights of earthworms in these three situations in Table 5. It is

Table 4. Dry weights of recognizable worm casts in tall chalk, under *Calluna* and under *Ulex*. Five plots of 50 × 50 cm sampled in each situation on 22–23 June 1970.

	Tall chalk heath	Under <i>Calluna</i>	Under <i>Ulex</i>
Mean weight per 2500 cm ² (± S.D.)	13.8 ± 11.7	3.8 ± 1.7	20.9 ± 10.0
pH range	(4.6*) 5.0–6.4	3.7–4.6	3.8–4.2

* The site of this sample might have been under *Ulex* for some years in the period 1954–64.

seen that *Calluna* inhibits earthworm activity. However, relatively large numbers of earthworms can be found under some *Calluna* bushes. One might suppose that this is because of the presence of a calcareous subsoil but many of the worms found under *Calluna* 2 in Table 5 were well up among the *Calluna* roots in soil of about pH 4.5. Unfortunately most of the worms we found were immature so that they could not be identified to species level. The majority of the mature worms under *Festuca* and *Ulex* have been identified by Dr T.D. Pearce as *Allolobophora chlorotica* (Savigny); a few *A. caliginosa* (Savigny)

Table 5. Numbers and dry weights of earthworms in soil under tall chalk heath, under *Calluna* and under *Ulex*. Plots of 50 × 50 cm, dug out to c. 25 cm depth and sorted by hand, 15–18 April 1970.

	Number of earthworms	Dry weight of earthworms (g)
Tall chalk heath 1	29	1.26
2	35	3.36
<i>Calluna</i> 1	2	0.60
2	31	2.40
<i>Ulex</i> 1	51	5.02
2	17	2.56

were also present. *Ulex* seems to stimulate earthworm activity, perhaps because it forms nitrogen-rich roots which are particularly attractive, when either alive or dead. The pH of most of the casts under *Ulex* is remarkably low (Table 4). Presumably the worms ingest earth mostly while they are in the uppermost few cm of soil and that is why the abundant casting does not generally reverse the acidification process. The species responsible for the surface-casting is not yet known. We have sometimes found casts of higher pH (5.5–6.1) under tall *Ulex* so that deeper soil is sometimes ingested; where earthworm activity is particularly intense, acidification may indeed be reversed (starred values in Fig. 7).

Acceleration of leaching

We can summarize the findings so far as follows. Immobilization does not appear to be a major factor in the case of *Ulex*; failure of deep-rooting and inhibition of earthworms do not apply. In contrast both these latter factors may be important for *Calluna* and go some way to explaining the difference between bases immobilized and bases lost. We do not think that these two factors are likely to account for most of the acidification by *Calluna* because they would be unlikely to produce the regular pattern of acidification that is

found (cf. Figs. 2, 3 and 7; also Fig. 8 in Grubb *et al.* 1969). Deep-rooted calcicoles were scattered irregularly in the original sward and earthworm activity is well known to be patchy at any one time. In contrast acidification shows a rather regular diminution in intensity from the centre of a bush outwards, with occasional outstanding values of pH where earthworms have recently been active (Fig. 7). The regular pattern could readily be produced by removal of bases either by uptake into roots or by accelerated leaching.

Discussion

We have shown that rapid acidification of chalk heath soil beneath bushes of *Calluna* and *Ulex* is effected by a removal of bases, particularly calcium, rather than by an addition of acid. It appears impossible to account for removal of calcium by *Calluna* and *Ulex* as due wholly to immobilization in the bushes and their litter; the position regarding *Ulex* is not yet clear. Inhibition of earthworms that bring up subsoil and failure to form deep roots probably play a part in acidification by *Calluna*, but there is possibly also an accelerated leaching of calcium down the profile.

Of the plant-induced soil changes described in the literature, that most closely resembling the acidification of a chalk heath soil seems to be the 'degradation' of a chernozem or prairie soil. Chernozems resemble chalk heath soils in their large store of exchangeable calcium; most are derived chiefly from loess and this makes the similarity to certain chalk heath soils, like the one at Lullington, especially close. Chernozems, like the chalk heath soils, are developed under a grass cover and, when they are invaded by trees, whether broad-leaved or coniferous, 'degraded chernozems' or leached groud soils begin to develop (Levchenko 1930; Tiurin 1930; Wilde 1958). The first stage seems to be acidification of the top soil, effected by leaching of bases, but we have not been able to trace any critical work on the mechanism of this leaching. When the pH of the top soil falls, some of the incorporated organic matter is mobilized and leached away. Oxides of iron and aluminium are also translocated. Eventually a strongly leached A₂ horizon and a spodic B horizon may develop (Wilde 1958). As yet we have no indisputable evidence that the development of the chalk heath soils is proceeding into the podsolization stage even under *Calluna* but it is notable that the humic substances do seem to be more readily leached from the acidified soils; this is readily seen when various soil extractions are made.

Acidification of soils initially very low in humus seems to proceed quite differently from acidification of soils rich in humus. The case investigated in most detail is that of podsollic soils in southern Australia being acidified under crops of *Trifolium subterraneum* fertilized with superphosphate; Williams & Donald (1957) found a marked increase in cation exchange capacity but a

much smaller increase in exchangeable calcium and so explained the drop in pH from 5.6–6.0 to 5.1–5.8. The nearest parallel under semi-natural vegetation concerns the succession on sand dunes; Salisbury (1952) found a parallel between a general increase in humus content and a general fall in pH. Salisbury (1925) and Wilson (1960) found substantial increases in humus content correlated with a rapid fall in pH under *Calluna*. Unfortunately no analyses of exchangeable calcium were given by these authors.

The forest soils, in which acidification by various trees has been studied, have generally been of moderate to low humus content. The chemical basis of acidification at most sites is quite unclear but the data given by Ovington (1953, 1956, 1958) for the top 5 cm of a brown forest soil at Bedgebury show evidence of both an increase in organic matter and a decrease in exchangeable calcium. It is notable that the amount of calcium lost from the top 50 cm of soil examined by Ovington was appreciably less than that immobilized in the crop and its litter. Many tree crops, including conifers, can, in fact, increase the amounts of exchangeable nutrients in the topsoil by the agency of their roots and litter, provided there is a suitable reservoir of unweathered minerals in the topsoil and/or an accessible subsoil (see Dimbleby 1952 and papers cited there). Much more critical information is needed on nutrient cycles under crops of trees that acidify the soil. The few relevant studies (e.g. Livens & Vanstellen 1956, 1957; Smirnova & Suhanova 1964) yield no conclusive evidence that accelerated leaching of calcium, of the type which seems to occur under *Calluna* on chalk heath soil, has any part in the acidification process in a forest soil. However, nobody yet seems to have compared the mineral contents of water draining from under, say, intact oak forest and planted pine, on a brown forest soil (*sol brun* or *sol brun lessivé*); accelerated leaching may indeed be very important in such situations.

If there is indeed an accelerated leaching of calcium, then great interest attaches to the mechanism concerned. Much may be learnt from the large volume of work done in the last 20 years on the complexing of iron and aluminium by organic molecules as a part of the podsolization process. A view widely favoured at present is that organic acids such as citric are chiefly responsible and that an essential feature of the podsolization process is an inhibition of the destruction of aliphatic acids under mor humus (see Bruckert & Jacquin 1969a and papers cited there). It is thought that phenolic materials may be responsible for the inhibition of microbial processes under mor (see Beck, Dommergues & van den Driessche 1969 and papers cited there) and that also they may play some part directly in translocation of iron and aluminium as organic complexes (see Bruckert & Jacquin 1969b and papers cited there). Little work has been done on translocation in the soil of calcium, magnesium or potassium. However, aliphatic acids such as citric certainly can leach these ions from the soil (Bruckert & Jacquin 1969a) and it

may be that the acidification of chalk heath soil by loss of bases under *Calluna* is effected by essentially the same mechanism as outlined above for podsolization (cf. increase in titratable acids in soil extracts, Table 1). According to this view the microbial population of the soil is likely to have a key role in acidification by *Calluna*. Rapid acidification of soils by increase in humus content, as under *Calluna* on sand dunes, is probably chiefly due to inhibition of the breakdown of humus by bacteria (cf. Beck *et al.* 1969), though it may be partly because the plant residues are richer in humus precursors, i.e. various polyphenols as well as lignin (cf. Hurst & Burges 1967). Any inhibition of the microbial population is likely to affect the supply of such key nutrients as nitrogen and phosphorus (cf. Beck *et al.* 1969) and it is highly desirable that our present study should be extended to investigate this aspect.

Ultimately we are concerned, in the context of management, to discover how best to prevent and reverse acidification of soils initially in the pH range 5–6. This work has only just begun to uncover the complex changes in soil chemistry and biology that are involved. However, it should be plain that certain types of management are unlikely to succeed in regenerating chalk heath soil. Addition of nitrogen, which can apparently reverse podsolization by stimulating a re-activation of the profile (Romell in Harley 1954) is unlikely to be effective in regenerating chalk heath soil because such a massive loss of calcium from the above-flints layer has taken place. Clearly ploughing is not admissible because the calcifuges would then be unable to recolonize the calcareous topsoil just as the calcicoles are lost under acidification. Possibly a carefully controlled addition of powdered chalk or lime water ($\text{Ca}(\text{OH})_2$) could be effective. We hope to try out this technique with the co-operation of the Nature Conservancy in the next year.

Acknowledgements

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Summary

Acidification is considered in the context of a specific problem in the management of a particular community (chalk heath). Chalk heath is an intimate mixture of calcicoles and calcifuges growing in a shallow loam over chalk (top soil pH 5–6). Since the virtual cessation of rabbit-grazing with myxomatosis in 1954, bushes of *Calluna* and *Ulex* have grown up and acidified the soil below them (top soil pH 3.5–5.0). When the *Ulex* scrub is cleared a mixture of calcifuges and indifferent species becomes established; the calcicoles cannot

return (Grubb *et al.* 1969). We have investigated first the mechanism of acidification. It seems that removal of bases is more important than addition of acids. We have investigated next certain functions of the cycling of bases in the community. It seems that the removal of bases by *Ulex* may be accounted for wholly by immobilization in the bushes and their litter whereas the removal by *Calluna* involves also a failure of deep rooting, an inhibition of earthworm activity and possibly an accelerated leaching. The results are discussed in relation to the few data in the literature on acidification of other soils and in relation to practical management.

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